

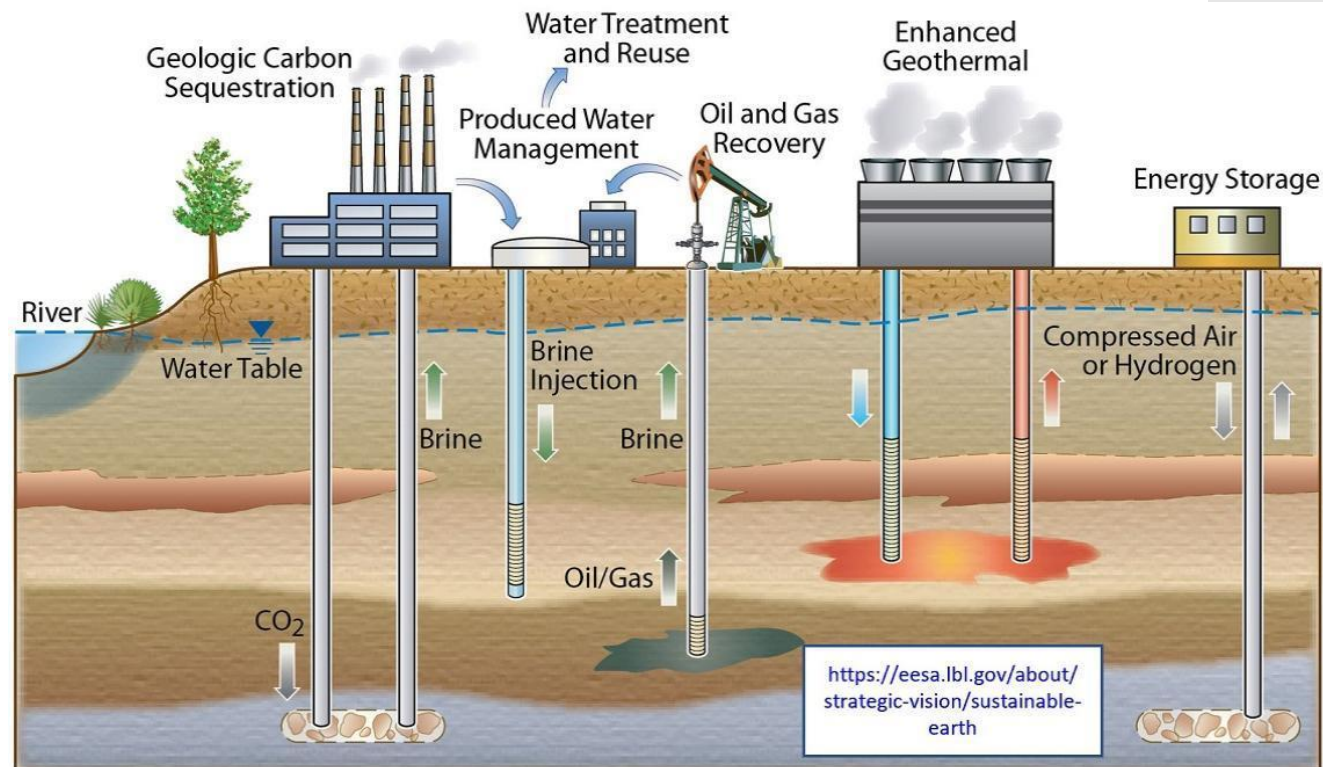
ML supported simulation in deep drilling technology

Gunther Brenner

Institut für Technische Mechanik

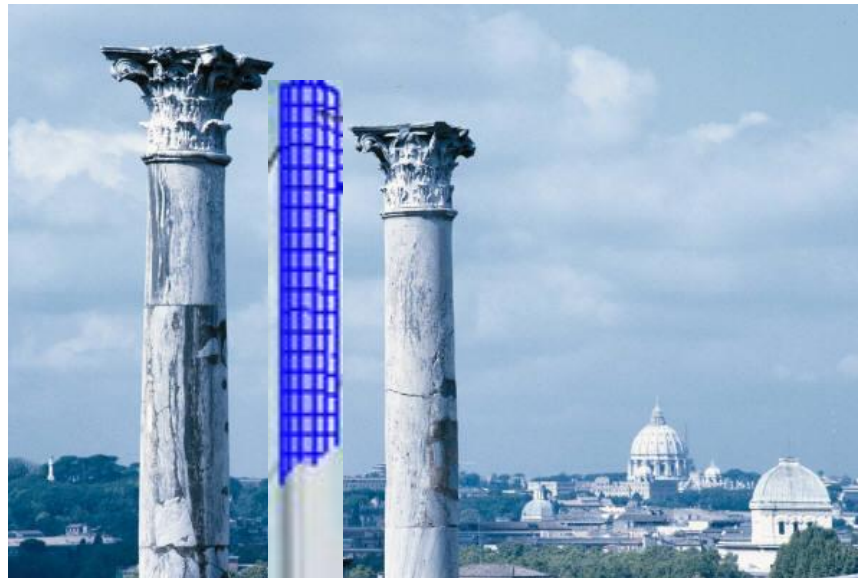
Drilling Simulator Cella

TU-Clausthal



Simulation: an attempt at a definition

- Historically: the two pillars of knowledge
experiment and **theory**
- Today: Simulation as the third pillar of knowledge



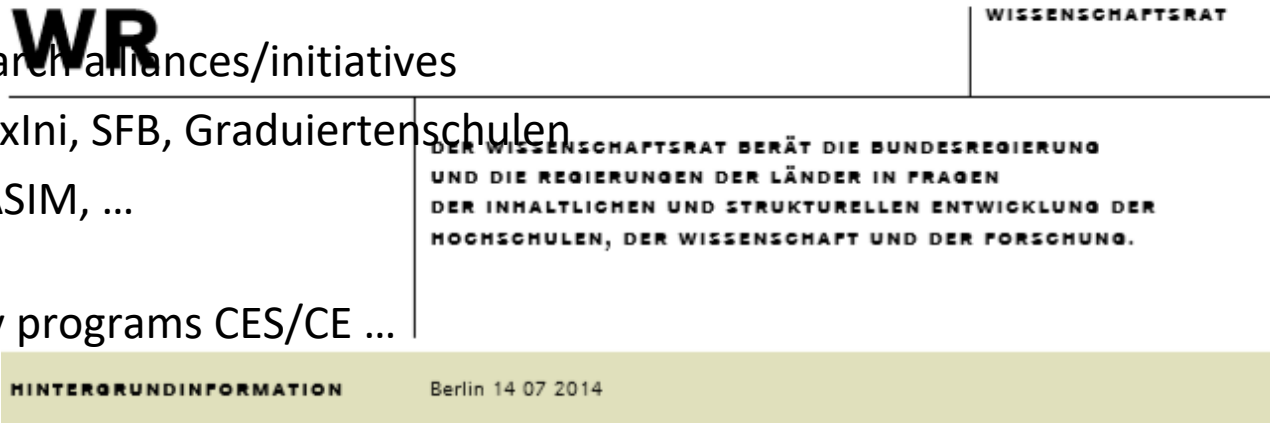
Simulation: Trends

- Simulation science as a new scientific discipline ?
 - White Paper WR 2014

- Research alliances/initiatives

- ExIni, SFB, Graduiertenschulen
- ASIM, ...

- Study programs CES/CE ...



ung und Weiterentwicklung

Als Simtech hast du null Fachkenntnis in andere Bereichen, sprich du bist ein "Fachidiot" der sich nur mit Simulation auskennt. Daher ist dieser Studiengang auch meiner Ansicht nach so stark begrenzt, was Studenten angeht.

Die wissen ganz genau, dass solche Leute nicht oft gebraucht werden.

Simulation: Etymologie / Use of Language

- **simulare** (lat.)
 - feign, fake, pretend, imitate
- **simulacrum** (lat.)
 - (divine) image, mirror image, dream image, idol, mirage
- **Medical psychology**
 - Simulation (Dissimulation) – Simulant
- **Acceptance** in technical circles ?
 - Example:

C omputational	C olors
F luid	F or
D ynamics	D irectors

Simulation: Definition

■ Technology

- Technical Committee 204 - Modeling and Simulation: **VDI 3633**

*„Simulation is the reproduction (...of the behavior...) of a **system** with its **dynamic** processes in an **experimental model** in order to **gain knowledge** that can be transferred to reality.“*

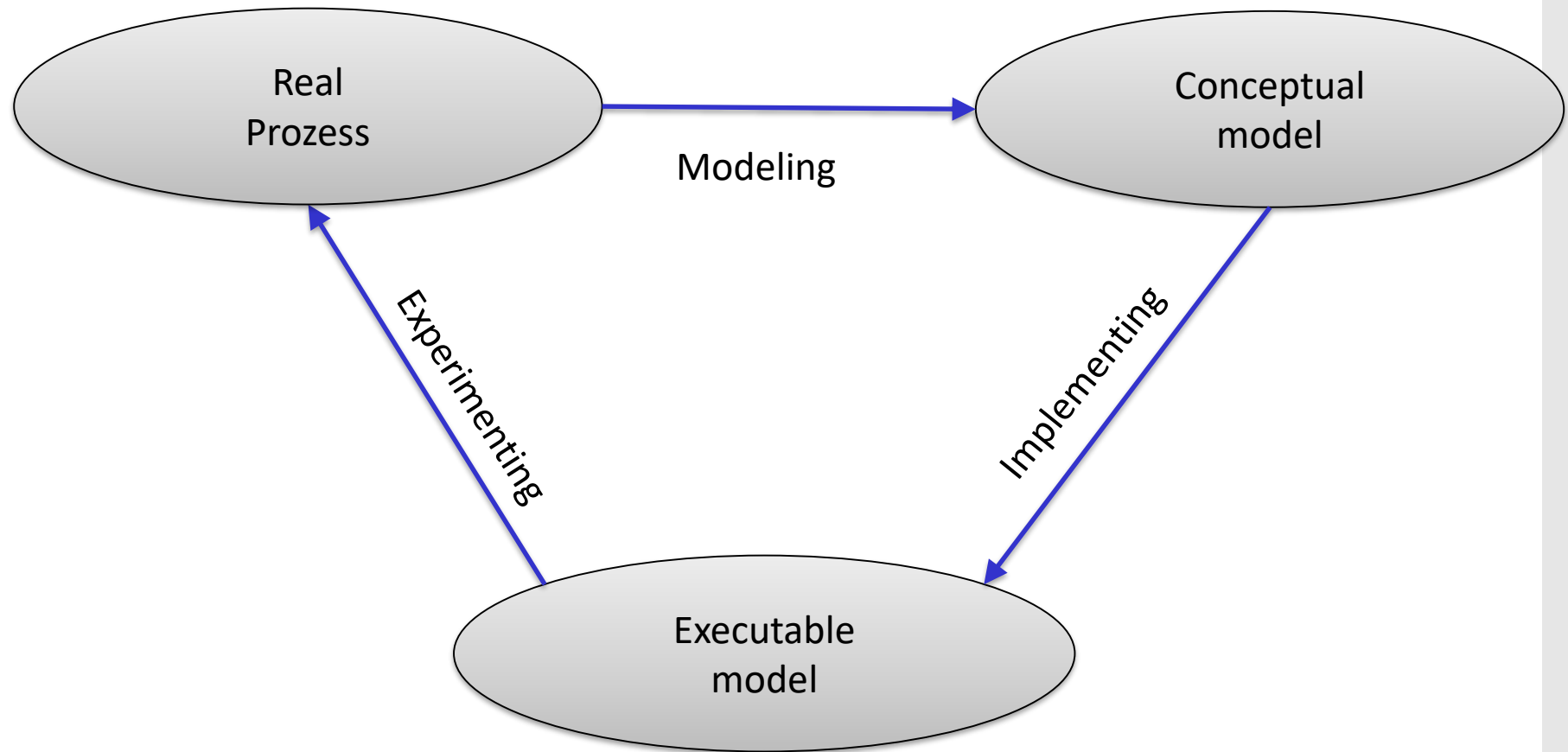
■ Simulation requires **modeling**

■ Computer Simulation

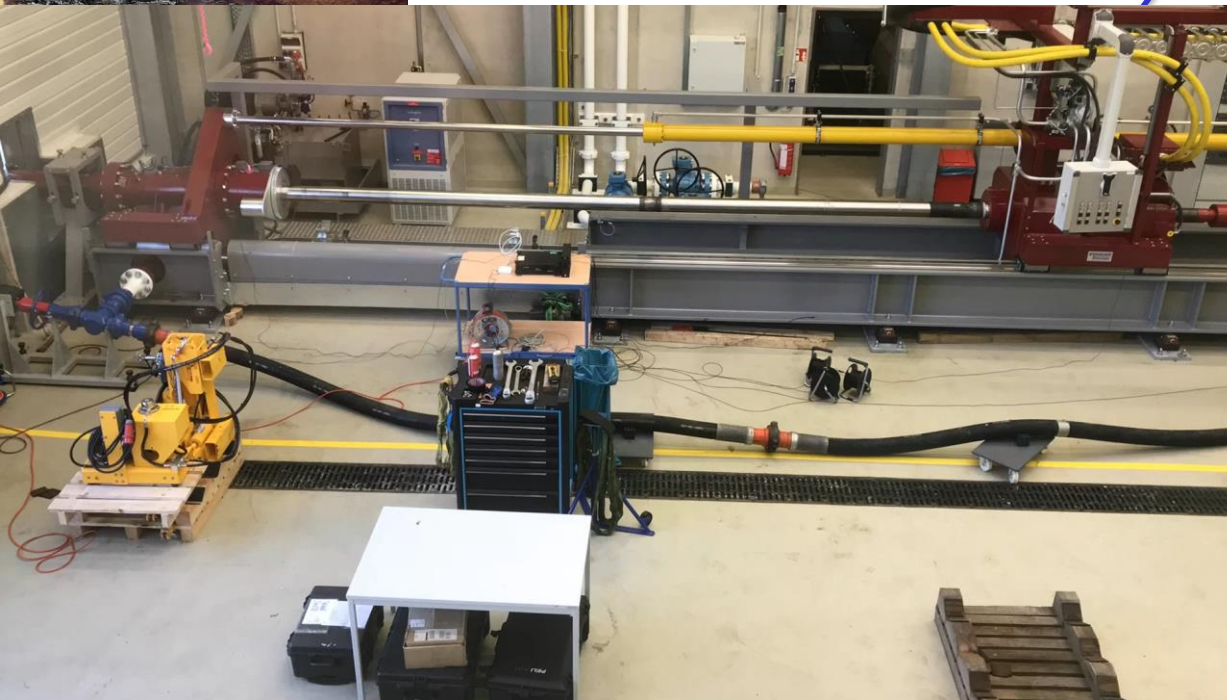
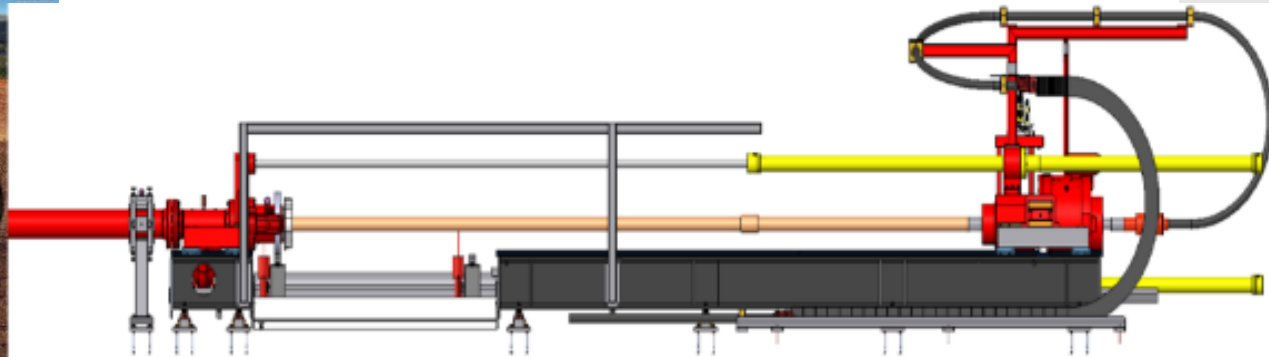
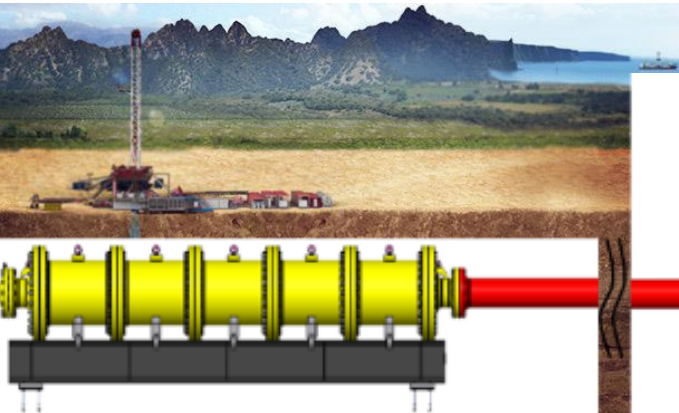
„In-silico“ Simulation

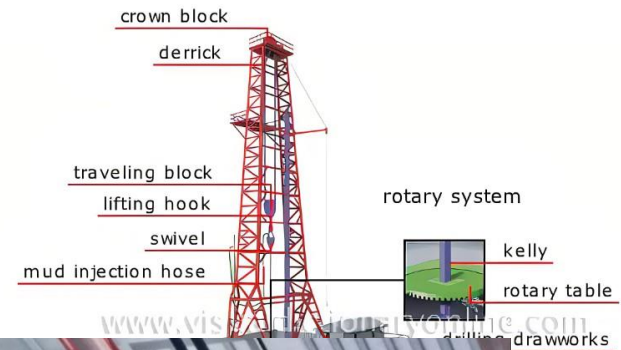
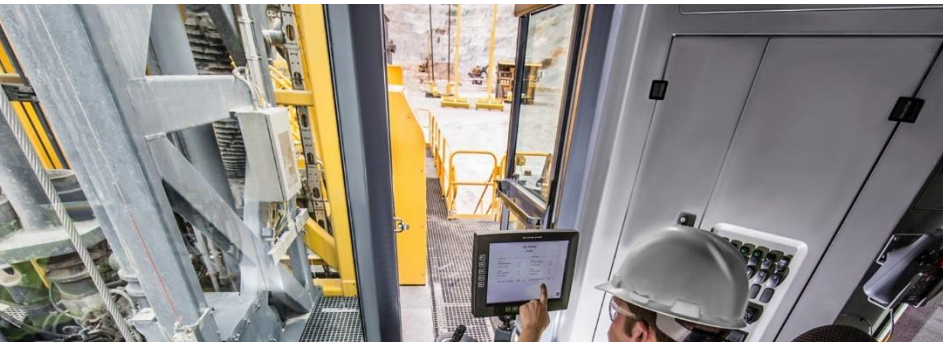
... is only one possible realization of simulation

Simulation in general



Simulation in deep drilling



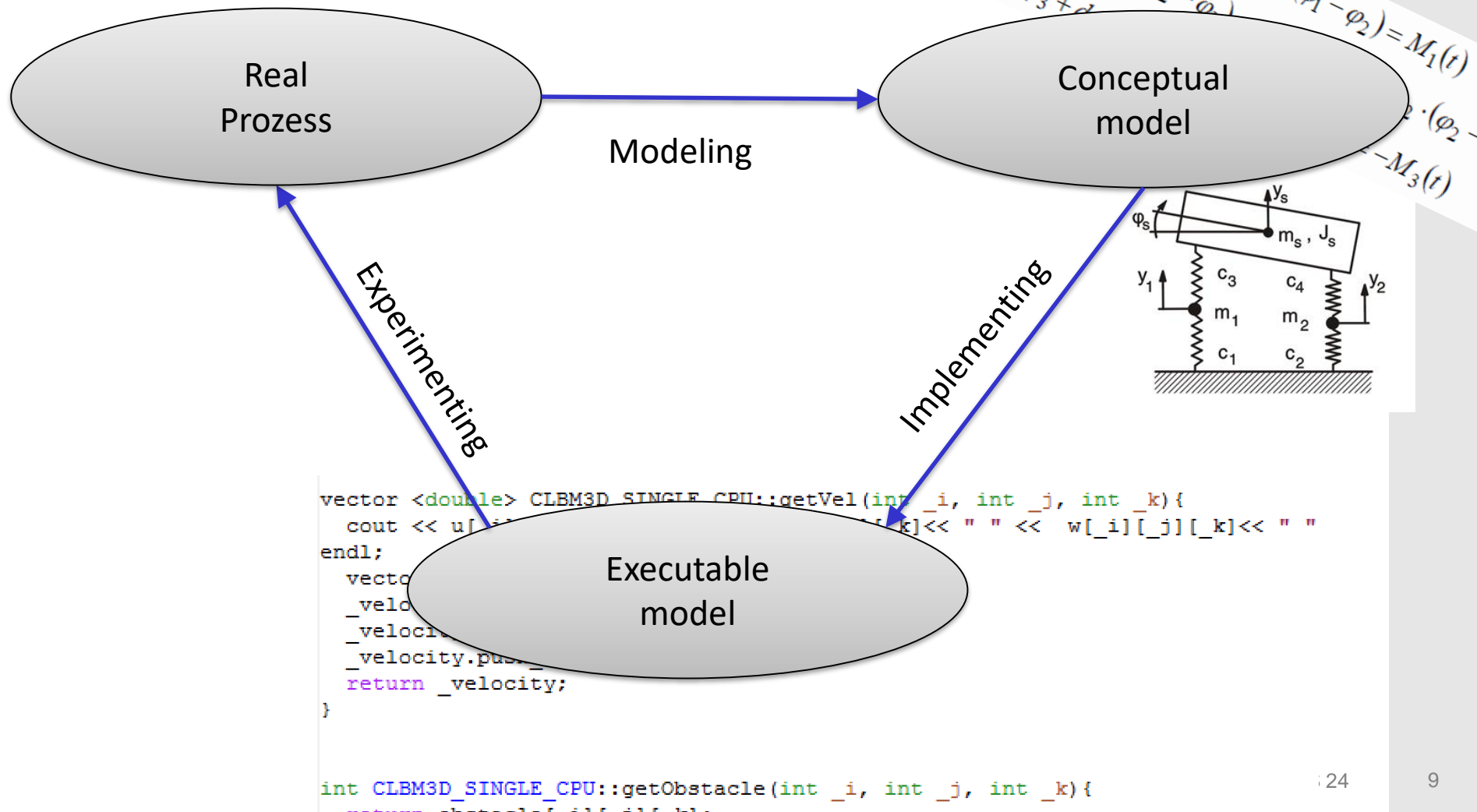


pump

id pit

vious rock

„in-silico“ simulation



Modeling and „in-silico“ simulation

Classical
approach

Based on

- Laws of physics (generally accepted)
 - Conservation of mass, momentum etc.
- Empiricism

Real
Prozess

Conceptual
model

Data
based

Based on

- Experiments
- (Computer)Simulations
- Real world measurements

Modeling „in-silico“ : two sides of the medal

„time to solution“ critical

„... as accurate as necessary“

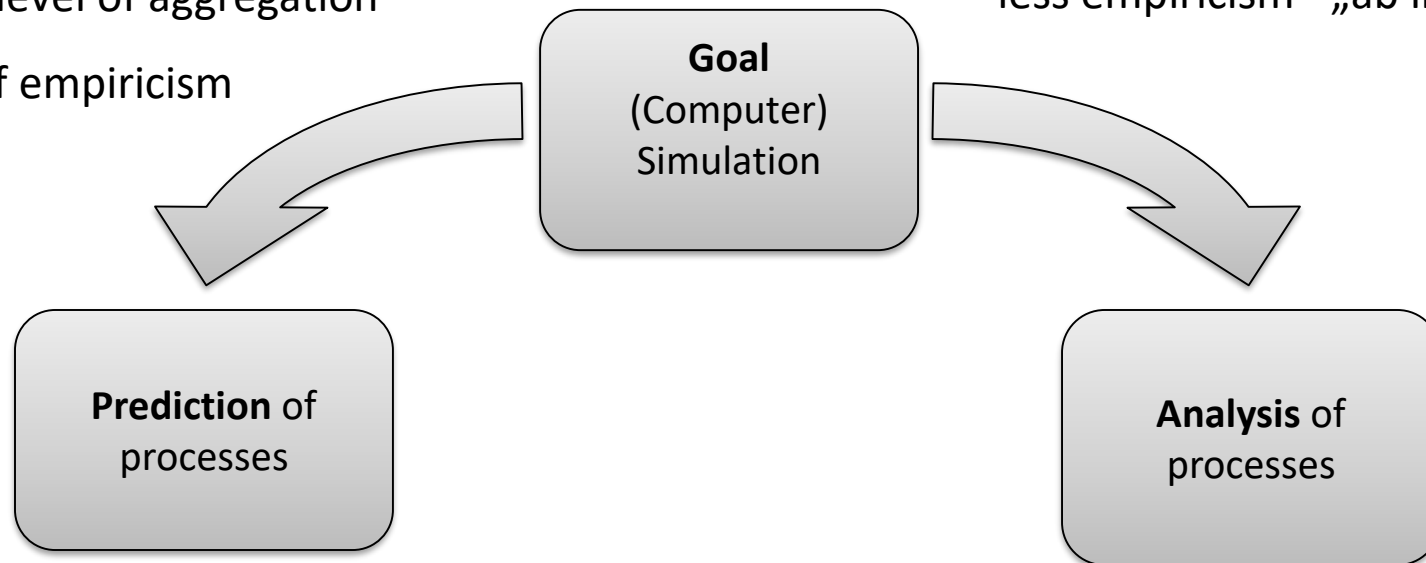
High level of aggregation

Lot of empiricism

realizability

high computational effort

less empiricism– „ab initio“

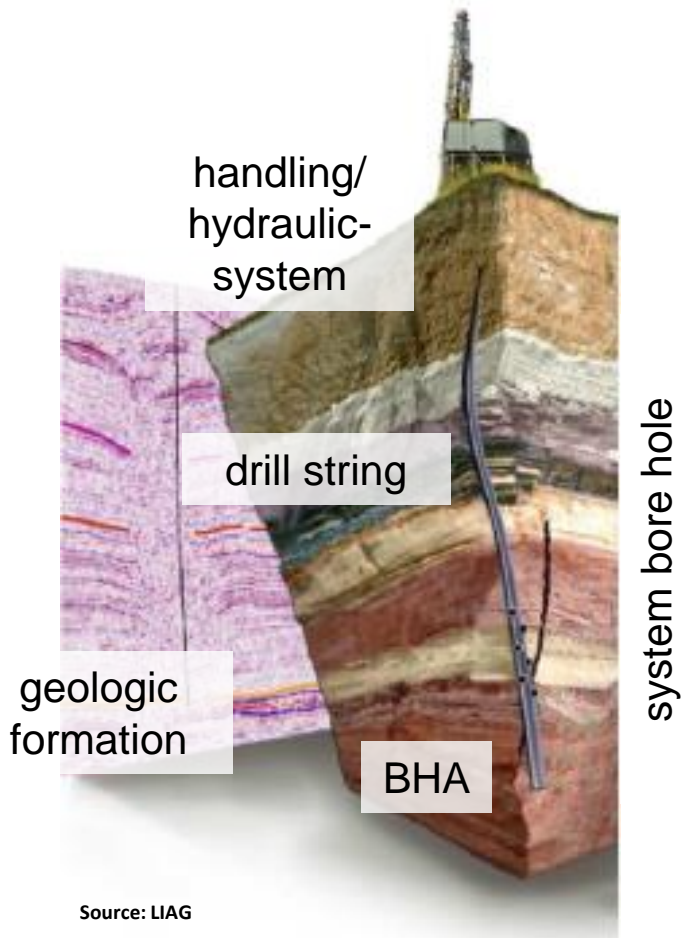


Deep drilling technology - deep geothermal energy/oil/natural gas extraction



Quelle: Stadtwerke München (SWM)

Modeling and simulation in deep drilling technology



The challenges

Production of boreholes 1,000 - 8,000 meters

- Economic risk
 - Minimization of the drilling risk 3,000 €/meter
 - Efficiency / time
- Ecological risk
 - Unknown geological formation
 - Integrity of the borehole

Vision

- Optimum process control
- Automation of the process
- Training of operating personnel

Monitoring and control of the drilling process through simulations

Modeling and simulation in deep drilling technology

Simulation/experiment for quantification
of phenomena

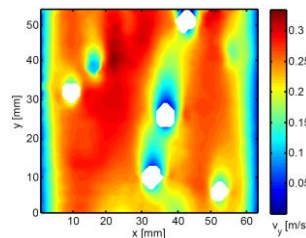
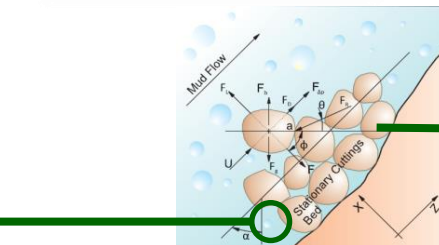
Simulation for
prediction,
optimization

granular flow
sedimentation

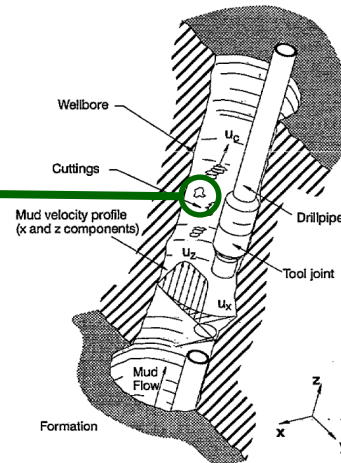
rheology



Microscale

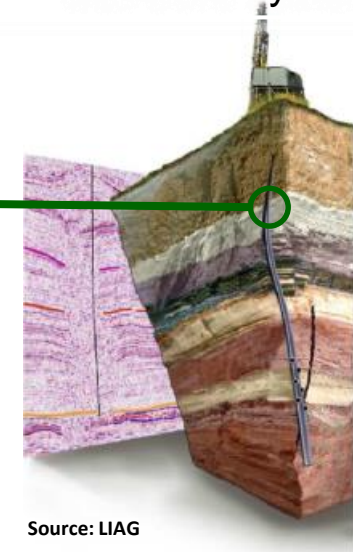


well-bore section
bottom-hole zone



Mesoscale

well-bore system



Source: LIAG

Macroscale

$<10^{-6}$

10^{-3}

10^0

10^3 meters

Modeling and simulation in deep drilling technology

- Multiphase flow (liquid - solid)
 - Wide particle size distribution, irregular particle shape, variable solids loading (<1% - densest packing)
 - possibly turbulence, moderate Re numbers
- Complex rheology
 - structurally viscous rinsing liquids, Tixotropy
- Variable ambient conditions and geometry
 - geological formation: temperature, rock parameters
 - drill string dynamics, rotation
 - gravity: vertical, inclined and horizontal distances
- **Aggregation of all relevant parameters in validated models is unclear**

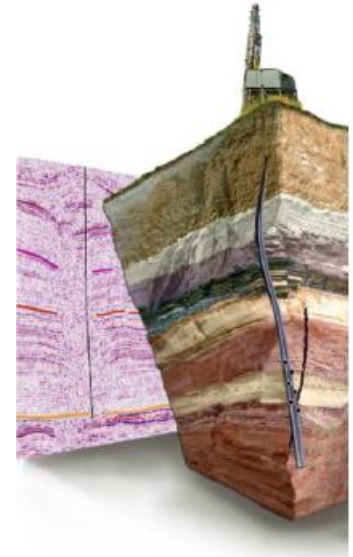
Modeling at macro or system level

■ Research Question

- Prediction of hydraulic system / cuttings transport
- Optimization of operational parameters
- Investigation of scenarios (start-up, safety and cf.)
- Monitoring in the field
- Automation of the drilling process

■ Methodology and models

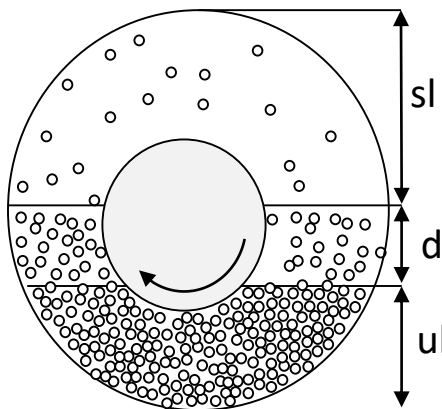
- 1D transport models (“driftflux” models for vertical conveying)
- 1 ½ D models (layer models for horizontal extraction)
- Coupling with geomodels
- Real-time capable if necessary



Modeling at macro or system level

■ Multilayer Model

Conservation of mass



suspension layer

$$\frac{\partial \rho_d \alpha_{d,sl}}{\partial t} + \frac{\partial \rho_d \alpha_{d,sl} V_{sl}}{\partial s} = +S_{sl-dl}$$

dl dispersed layer

$$\frac{\partial \rho_d \alpha_{d,dl}}{\partial t} + \frac{\partial \rho_d \alpha_{d,dl} V_{dl}}{\partial s} = +S_{dl-sl} + S_{dl-ul}$$

uniform layer

$$\frac{\partial \rho_d \alpha_{d,ul}}{\partial t} + \frac{\partial \rho_d \alpha_{d,ul} V_{ul}}{\partial s} = +S_{ul-dl}$$

$$S_{l-l} \approx f(\alpha, V, \text{Partikel}, \text{Geometrie}, \text{Rheologie}, \text{Rotation}, \dots)$$

Modeling at the mesoscopic level

■ Research Question

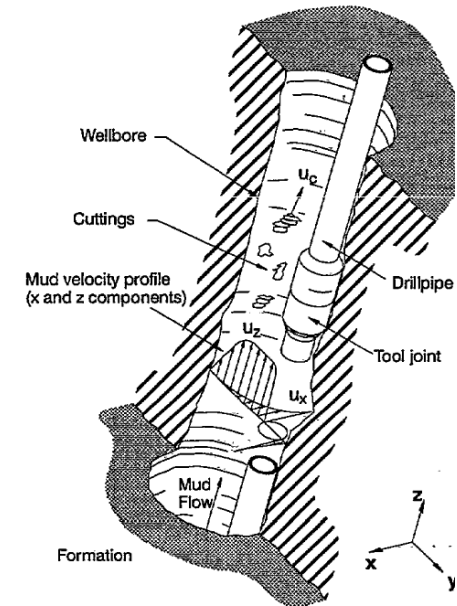
- Quantification of parameters in models at macro level, e.g. transport efficiency
- “Scale-bridging” between macro-models and meso-models/measurements

■ Simulation by experiment

- Multiphase test bench
- PIV / PTV measurement simultaneous velocity of the continuous and disperse phase

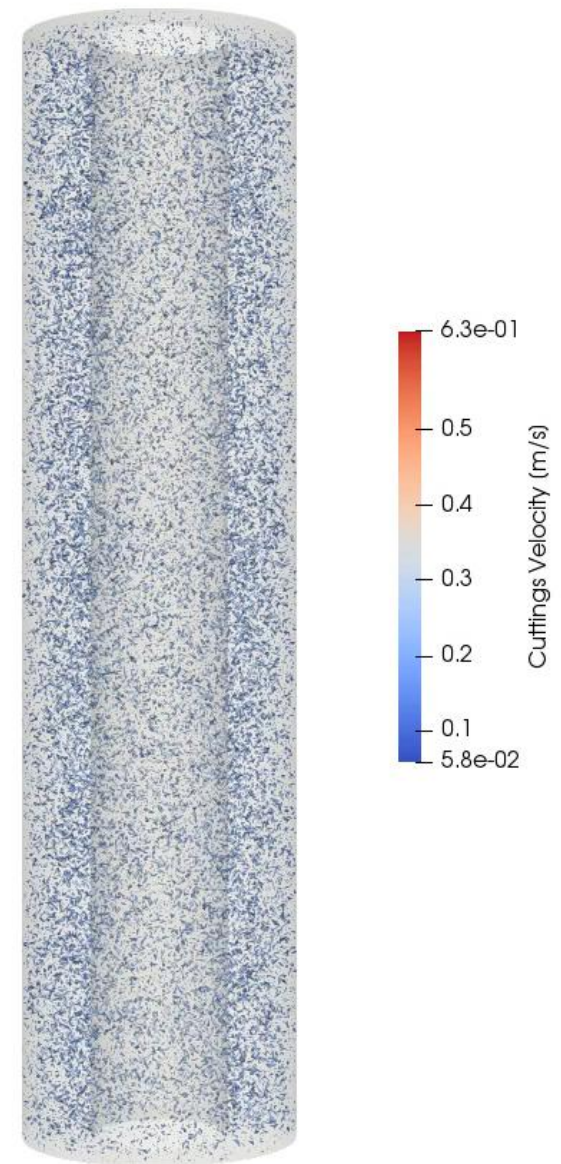
■ Numerical simulation

- CFD-DEM (coupling with discrete element method)
Basis: OpenFOAM / LIGGGHTS



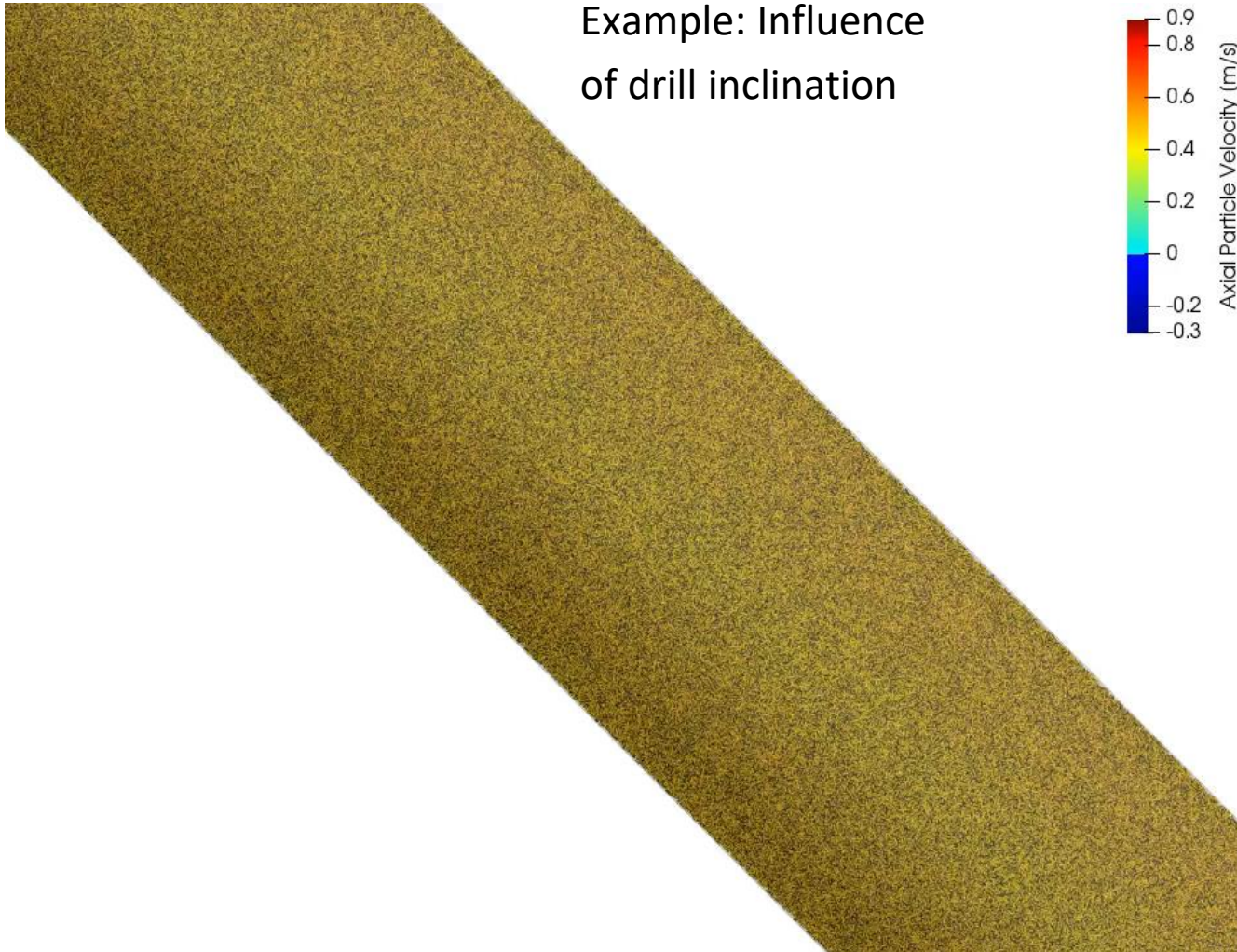
Numerical calculation on a mesoscopic level

- Example: Influence of drill string rotation



Numerical calculation on a mesoscopic level

Example: Influence
of drill inclination



Experiments at the mesoscopic level:

Spherical particles

Soda lime glass and borosilicate glass

$$d_p = 1,5 - 5 \text{ mm}$$

Fluids

White oil

Water / Polymers

Suspension

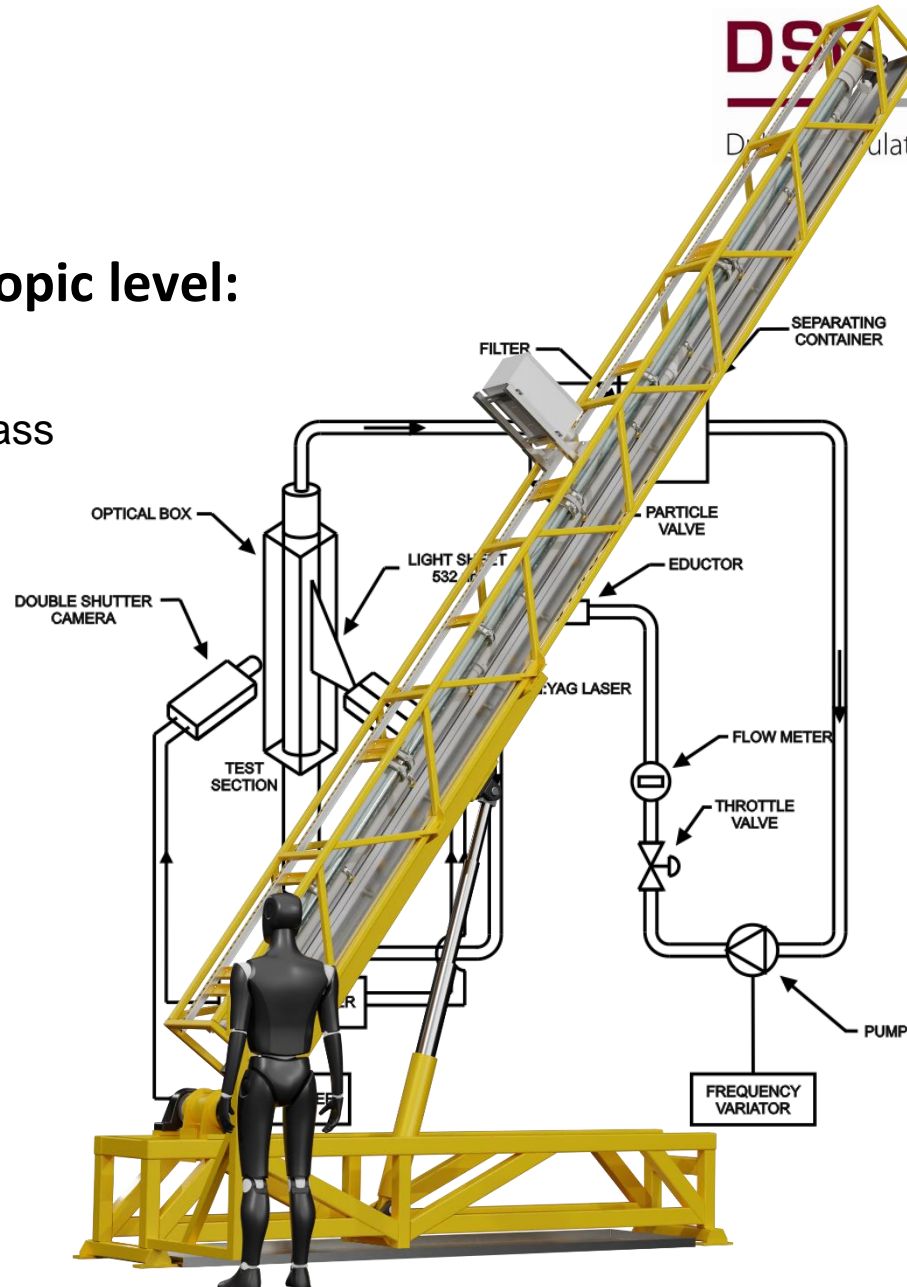
Loading < 5%

mono- / bidisperse distribution

Parameters

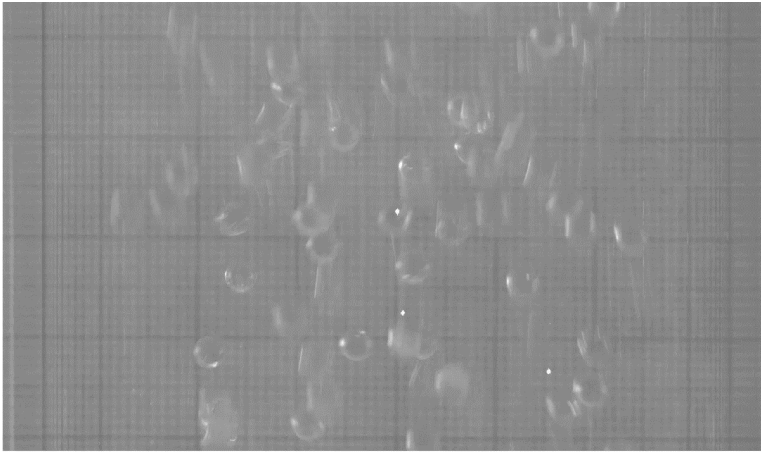
$$Re_D < 300 \quad D/d_p \sim 10 - 30$$

$$Re_p < 20 \quad \rho_p/\rho_f \sim 3$$

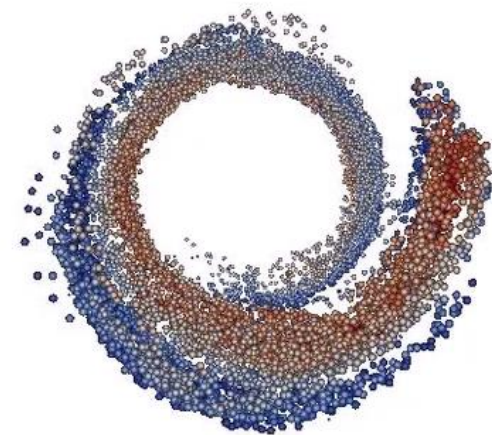
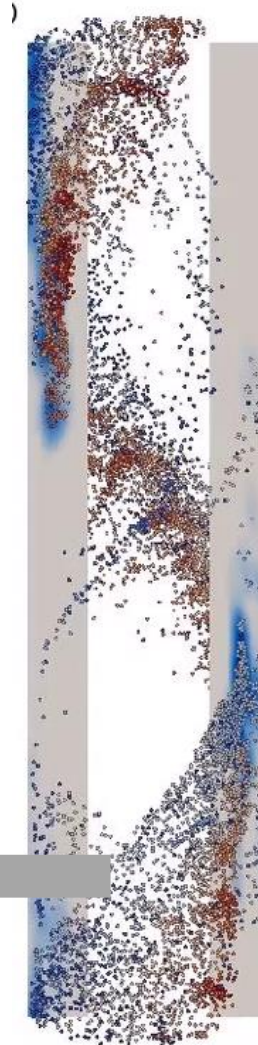


ARAGALL, R., V. MULCHANDANI, G. BRENNER; Optical measurement and numerical analysis of mono- and bidisperse coarse suspensions in vertical axisymmetric sudden-expansion, International Journal of Multiphase Flow, 69, 2015, pp. 63–80

Experiments and simulation at the mesoscopic level



Generic experiment
in the laboratory



Numerical
„Experiments“

Aggregated Models
Using Machine Learning

Evaluation of simulation/experiment

DEM
Simulation

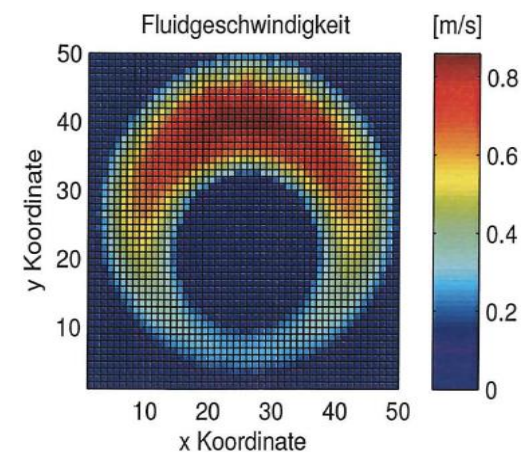
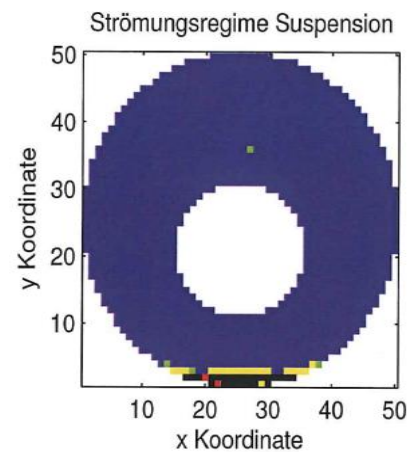
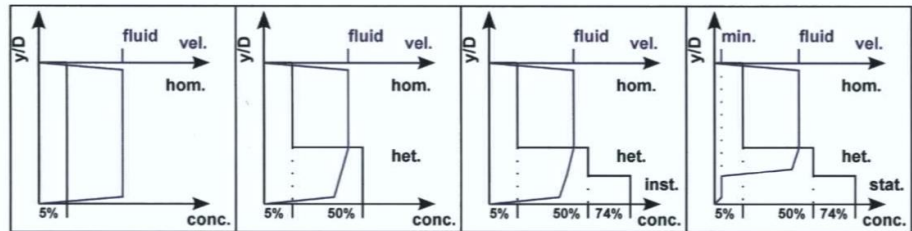
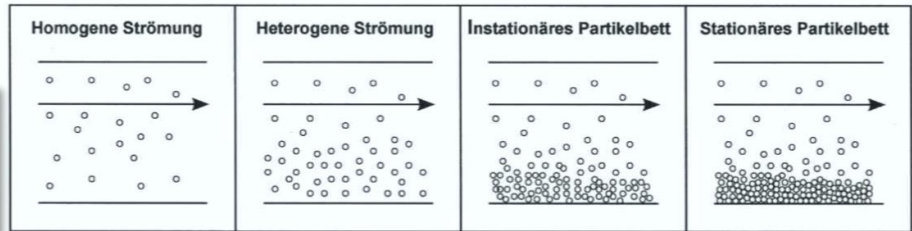
PIV/PTV
Experiment

Preprocessing

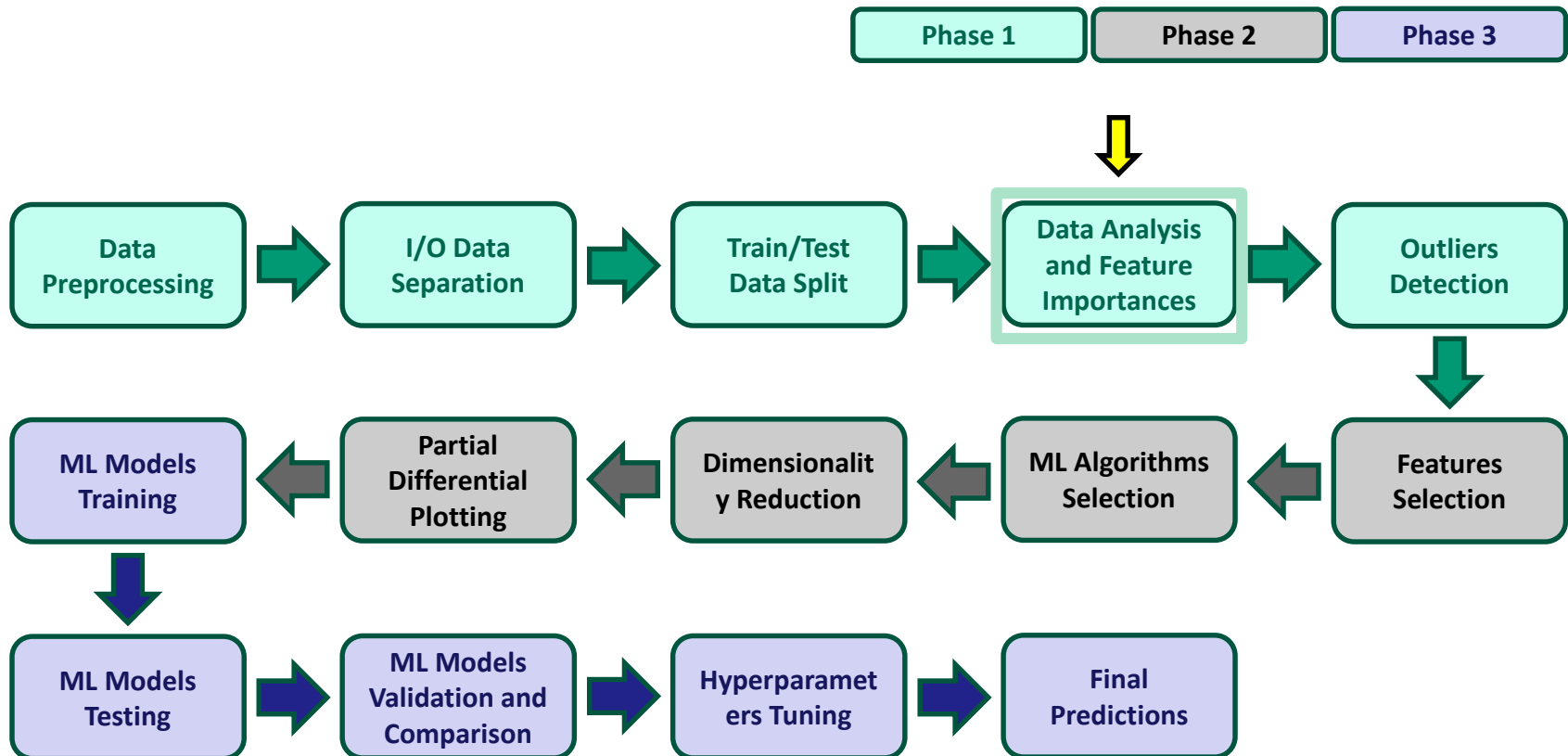
$$V_{dj} = \frac{\overline{\epsilon_p v_{pj}}}{E_p}$$

$$C_0 = \frac{\overline{\epsilon_p J_M}}{E_p V_M}$$

Model
Aggregation



ML Modeling



ML: Data analysis and feature importance from 20 simulations runs

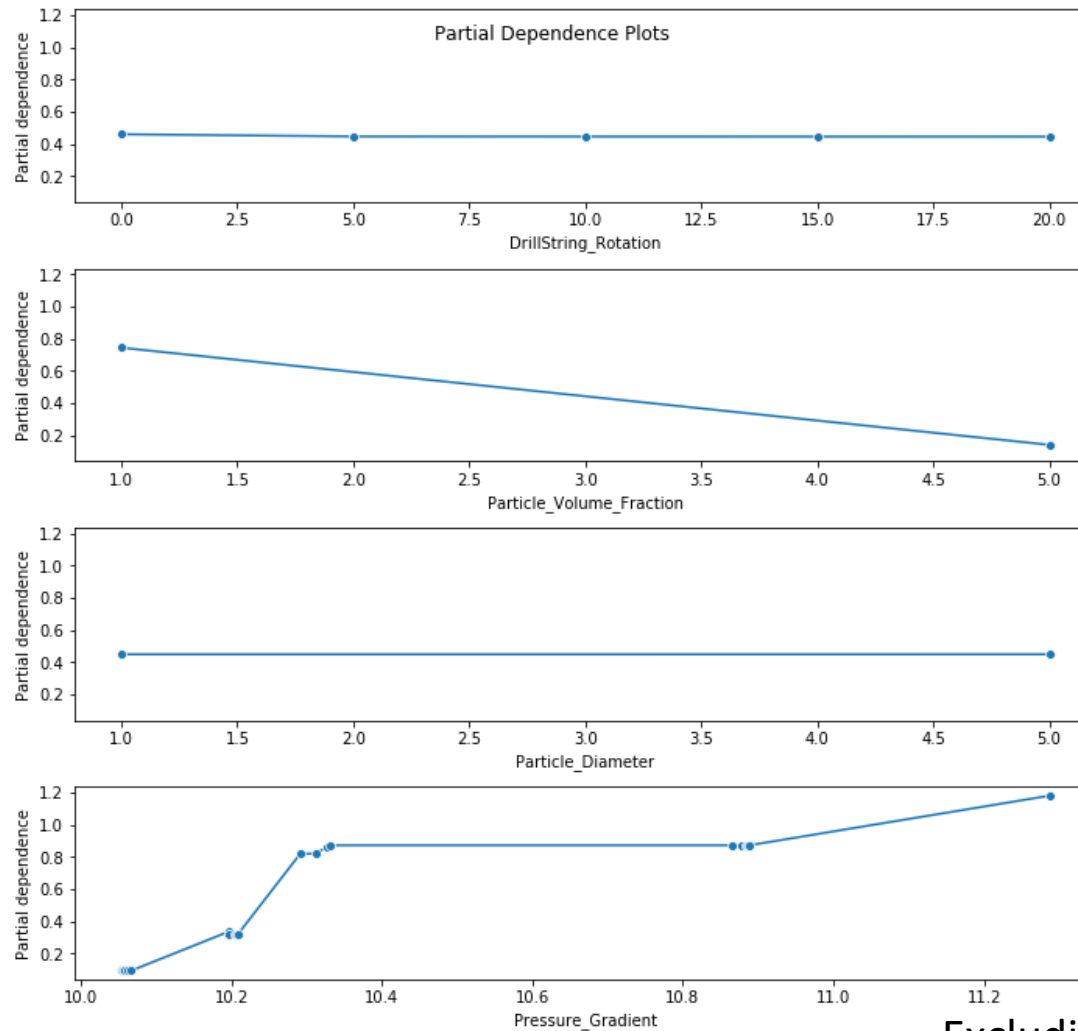
Parameter	Min.	Max.	Range	SD	Variance
Mean Fluid Velocity (m/s)	0.1	1	0.9	0.37043	0.137218
Drill String Rotation (1/s)	0	20	20	7.571712	57.33083
Particle Volume Fraction (-)	1	5	4	1.835326	3.368421
Particle Diameter (mm)	1	5	4	1.835326	3.368421
Pressure Gradient (Pa/m)	10.0539	11.2867	1.2328	0.370504	0.137273
Pressure Gradient Without Gravity (m/s ²)	0.2439	1.4767	1.2328	0.370504	0.137273
Pressure (Pa)	10.0528	11.2939	1.2411	0.370231	0.137071
Particle Velocity (m/s)	0.085826	1.245533	1.159707	0.442317	0.195645

ML: Parameters Correlations w.r.t Particle Velocity

Parameter	Pearson	Spearman
Mean Fluid Velocity	0.988	0.919
Drill String Rotation	-0.287	-0.388
Particle Volume Fraction	-0.273	-0.558
Particle Diameter	0.147	0.364
Pressure Gradient	0.035	-0.029
Pressure Gradient Without Gravity	0.035	-0.029
Pressure	0.035	-0.031
Particle Velocity	1	1

ML: Partial Dependence Plots – XGBoost Algorithm

Particle Velocity

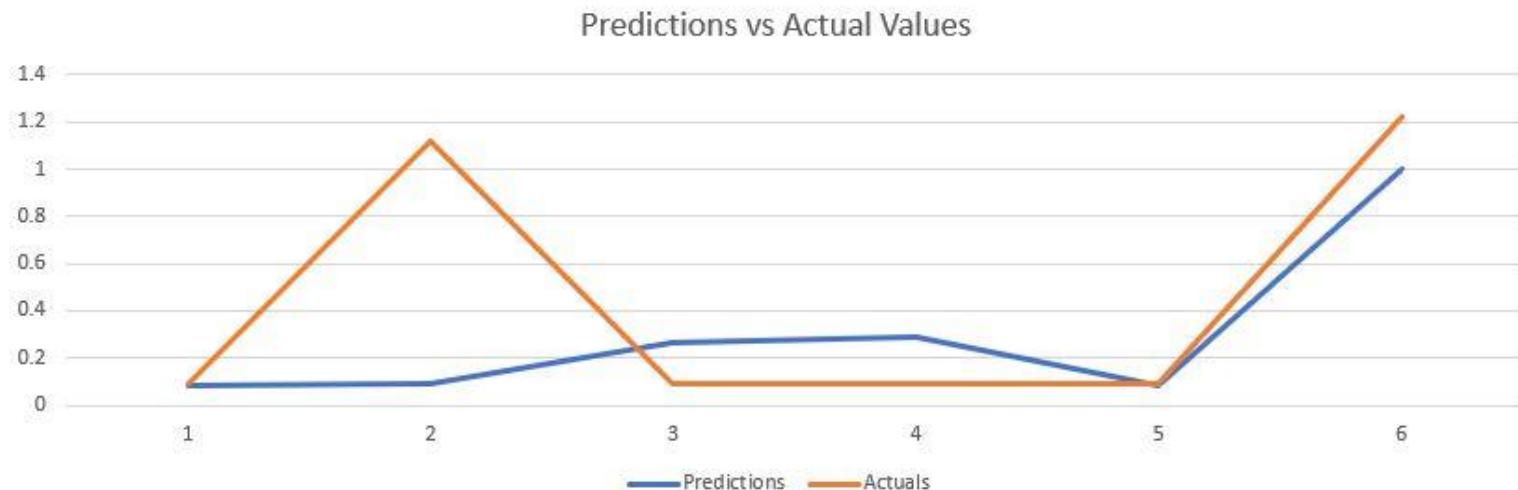


Excluding Axial Velocity

ML: Modeling Predictions – Random Forest Algorithm

- comparison between the predicted and actual values of the trained model
- blue line represents the predicted values
- orange line represents the original values
- model has been trained on a very small amount of data, therefore, the number of predictions is also small
- variations between insufficient learning data, yet

Particle Velocity



Summary

What can numerical simulations and ML do in deep drilling technology?

- Prediction of processes
 - often faster and more accurate than in experiments
 - Parameter variations can be set and evaluated more selectively
- Analysis of processes
 - Detailed information on all scales
 - Visualization / analysis of phenomena
 - Analyze sensitivities
 - Systematic aggregation of data
- Efficient and fast models for system simulation

Thanks

For your engagement

Kathrin Skinder, M.Sc. ITM

Khizar Shahid, M.Sc., DSC

Mohamad Moghadasi, M.Sc., DSC

Hozan Ibrahim, M.Sc., DSC

Roger Aragall, Dr.-Ing., Baker Hughes

You, for your attention

For financial support

DFG Deutsche
Forschungsgemeinschaft



**Niedersächsisches Ministerium
für Wissenschaft und Kultur**



Volkswagen**Stiftung**

Baker Hughes 

